HYBRID OPTIMISATION ELECTROMAGNETIC INTERFERENCE SHIELDING EFFECTIVENESS: MECHANICAL AND PHYSICAL PERFORMANCE OF PLASTER MORTAR CONTAINING PALM OIL FUEL ASH USING TAGUCHI GREY AND TAGUCHI-FLOWER POLLINATION ALGORITHM METHODS

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I dedicate this Ph.D. thesis to my parents, Oh Lai Ching and Ejem A/P Din Tong whom has provided me with unconditional love and support and have always been there for me throughout this journey.

ขอมอบความสำเร็จของงานวิจัยปริญญาเอกนี้ให้กับพ่อแม่คือนายเฉ้งและนางยิ้มที่มอบความรัก
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ABSTRACT

The rapid development of wireless telecommunications has revolutionarily modernized the global society, whereas it has created serious concerns on harmful effects of the electromagnetic interference (EMI) on human health and performance of electronic devices. The purpose of this research was to use palm oil fuel ash (POFA) as cement filler in plastering mortar to overcome the EMI issue. This research adopted Taguchi method with mix level design (L_{16} (4^4 2^2)) to examined the EMI shielding effectiveness (SE), mechanical properties and physical properties of the mortar. Six factors namely POFA admixture percentage, topcoat powder /binder ratio (TP/B), water/binder ratio (W/B), latex agent content (LA), the particle size of POFA and curing condition are used to control the nine responses. Pre-experiment data is optimized based on Taguchi-grey and Flower Pollination Algorithm (FPA) methods. The feasibility of the optimization was evaluated by repeating the experiments. Initially, the POFA was refined and segregated into 4 different layers. Layer 1 POFA performed highest SE with 25.76 dB at 1 GHz where the SE was decreased in accordance with the sequence of POFA layers. The SEM image of POFA showed the existence of cenosphere particles and it has potential in EMI SE due to the hollow spherical shape. Regression and ANOVA analysis demonstrated the optimal mixture from Taguchi-grey method is able to give additional 6 dB of SE compare to plaster mortar without POFA. Meanwhile, the optimal mixture from Taguchi-FPA able to give additional 5 dB of SE. It’s found that this does not affect its mechanical and physical properties because the confirmation results proved that all responses are within the range that specified in the standards. Finally, this research successfully employed POFA as cement filler for plastering mortar which can mitigate the EMI. The increase in the SE is due to the carbon content and spherical cenosphere particle in the POFA that promote multiple reflections. The implementation of Taguchi-grey and Taguchi-FPA methods successfully obtained optimal factors in order to improve SE and remaining protection of mechanical and physical properties in plaster mortar.

ABSTRAK

Perkembangan telekomunikasi tanpa wayar yang pesat telah dimodernisasi oleh masyarakat seluruh dunia, tetapi ia telah menimbulkan kebimbangan serius terhadap kesan berbahaya gangguan elektromagnetik (EMI) terhadap kesihatan manusia dan prestasi peranti elektronik. Tujuan kajian ini adalah untuk menggunakan abu bahan api kelapa sawit (POFA) sebagai pengisi simen dalam plastering mortar untuk mengatasi masalah EMI. Kajian ini menggunakan kaedah Taguchi dengan rekabentuk tahap campuran (L_{16} (4^4 2^2)) untuk mengkaji keberkesanan perisai (SE) EMI, sifat mekanikal dan sifat fizikal mortar. Enam faktor kawalan iaitu peratusan POFA, nisbah serbuk *topcoat*/pengikat (TP/B), nisbah air/pengikat (W/B), kandungan agen lateks (LA), saiz zarah POFA dan keadaan pengawetan digunakan untuk mengawal kesembilan tindak balas. Data pra-eksperimen dioptimumkan berdasarkan kaedah Taguchi-grey and Algoritma Pendebungaan (FPA). Kelayakan pengoptimuman telah dinilai dengan mengulang eksperimen. Pada mulanya, POFA ditapis dan diasingkan menjadi 4 lapisan berbeza. POFA lapisan 1 mencatat SE tertinggi dengan 25.76 dB pada 1 GHz di mana SE menurun mengikut turutan lapisan POFA. Imej SEM POFA menunjukkan kewujudan zarah cenosphere dan ia berpotensi dalam EMI SE kerana bentuk sfera berongga. Analisis regresi dan ANOVA menunjukkan campuran yang optimum dari kaedah Taguchi-grey dapat meningkatkan 6 dB SE berbanding mortar plaster tanpa POFA. Sementara itu, campuran optimum dari Taguchi-FPA mampu meningkatkan 5 dB SE. Kaedah ini tidak menjejaskan sifat mekanikal dan fizikalnya kerana hasil pengesahan eksperimen membuktikan bahawa semua tindak balas berada dalam julat yang dinyatakan dalam piawai. Akhirnya, penyelidikan ini berjaya menggunakan POFA sebagai pengisi simen untuk plastering mortar yang dapat mengurangkan EMI. Peningkatan SE adalah disebabkan oleh kandungan karbon dan zarah cenosphere bentuk sfera di POFA yang berlaku pelbagai refleksi. Pelaksanaan kaedah Taguchi-grey dan Taguchi-FPA berjaya memperolehi factor kawalan yang optimum untuk meningkatkan SE serta melindungi sifat mekanikal dan fizikal plaster mortar.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	-	Air content
A_{dB}	-	Absorption Loss (dB)
AlO_3	-	Aluminum Oxide
CaO	-	Calcium oxide
CS	-	Compressive strength
d	-	Largest dimension of the antenna (m)
DS	-	Drying shrinkage
E	-	Electric Field Intensity (V/m)
$\hat{E}_1$	-	Incident Electric Field within the Barrier (V/m)
$\hat{E}_2$	-	Reflected Electric Field within the Barrier (V/m)
E_i	-	Incident Electric Field
$\hat{E}_i$	-	Incident Electric Field (V/m)
EMC	-	Electromagnetic Compatibility
EMF	-	Electromagnetic Fields
EMI	-	Electromagnetic Interference
EMI SE	-	Electromagnetic interference shielding effectiveness
EMP	-	Electromagnetic Pulse
EMW	-	Electromagnetic Wave
$\hat{E}_r$	-	Reflected Electric Field (V/m)
E_t	-	Transmitted Electric Field
$\hat{E}_t$	-	Transmitted Electric Field (V/m)
FPA	-	Flower Pollination Algorithm
FS	-	Flexural strength
GRG	-	Grey gelation grade
H	-	Magnetic Field Intensity (A/m)
$\hat{H}_1$	-	Incident Magnetic Field within the Barrier (A/m)
$\hat{H}_2$	-	Reflected Magnetic Field within the Barrier (A/m)

H_i	-	Incident Magnetic Field
$\hat{H}_i$	-	Incident Magnetic Field (A/m)
HPEM	-	High-Power Electromagnetic
$\hat{H}_r$	-	Reflected Magnetic Field (A/m)
H_t	-	Transmitted Magnetic Field
$\hat{H}_t$	-	Transmitted Magnetic Field (A/m)
K_2O	-	Potassium oxide
LOI	-	Loss of ignition
LT	-	Loss Tangent
m^2/kg	-	Unit Blain Fineness
MC	-	Moisture Content
M_{dB}	-	Multiple reflection Loss (dB)
MgO	-	Magnesium oxide
MPOB	-	Malaysian Palm Oil Board
MUT	-	Material Under Test
MW	-	Microwave
NA	-	Network Analyzer
Na_2O	-	Sodium oxide
P_2O_5	-	Phosphorus pentoxide
POFA	-	Palm oil fuel/fly ash
r	-	Distance from the Source
R_{dB}	-	Reflection Loss (dB)
RF	-	Radio Frequency
SAR	-	Specific Absorption Rate
SE	-	Shielding Effectiveness
SiO_2	-	Silicon dioxide
SL	-	Slump Flow
SO_3	-	Sulphur trioxide
ST_fn	-	Final setting time
ST_in	-	Initial setting time
t	-	Thickness (m)
W/m^2	-	Unit of density
WHO	-	World Health Organization
WR	-	Water retention

Z_w	-	Wave Impedance (Ω)
α	-	Attenuation Constant (dimensionless)
δ	-	Skin Depth (m)
η_o	-	Intrinsic impedance of the free space
λ_o	-	Wavelength in Free Space (m)
μ_o	-	Relative Permeability of Free-Space (μ_o =4π x 10^{-7}H/m)
μr	-	Relative Permeability of Material (dimensionless)
σ	-	Conductivity (S/m)
$\mathcal{E}$	-	Permittivity (F/m)
$\mathcal{E}_*$	-	Complex Relative Permittivity
$\mathcal{E}_0$	-	Relative Permittivity of Free-Space ($\mathcal{E}_0$ = 8.854 x 10^{-12}F/m)
$\mathcal{E}_r$	-	Dielectric Constant (dimensionless)
γ	-	Propagation Constant
η	-	Characteristic Impedance of Material
η_0	-	Intrinsic Impedance of Free Space (120π Ω)
μ	-	Permeability (H/m)
μ_*	-	Complex Relative Permeability

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CHAPTER 1

INTRODUCTION

This chapter briefly presents the introduction of research. The chapter comprises of a research background, research problem statement, research objectives, research scopes, and research significance.

1.1 Background of research

As the result of industrial revolution and technology advancement, wireless communication systems such as telecommunication system, mobile phone networks, radar systems and so on are polluting our surrounding by emitting electromagnetic wave (EMW) (Levitt & Lai, 2010; Sun *et al.*, 2016). Table 1.1 lists down the electric field and a magnetic field strength of different household appliances at various distances published by World Health Organisation (WHO) (WHO, 2016 and Yee, 2015). Unconsciously, this is resulting in electromagnetic interference (EMI) (Fesenko, *et al.*, 1999; Ma, *et al.*, 2016; Smolenski, *et al.*, 2014; Yee, Sia, & Jenu, 2014). Electromagnetic interference (EMI) is the disruption of operation of electronic devices in the vicinity of an electromagnetic field (EM field) (Cao & Chung, 2004; Dou, *et al.*, 2007; Fesenko *et al.*, 1999; Khushnood *et al.*, 2015). Devices like cordless telephones, home entertainment systems, computers, and certain medical devices can fail to work properly in the presence of EMI (Cao & Chung, 2004; Fesenko *et al.*, 1999; Miszczyk & Darowicki, 2011).

Besides interrupting the operation of electrical and electronic system, EMI exposure is also harmful to human beings (Beall, *et al.*, 1996; Levitt & Lai, 2010; Loomis & Savitz, 1990; Xie, *et al.*, 2016; Yee *et al.*, 2014). A high-frequency range of electromagnetic wave was reported to increase approximately 1 to 5 °C of human body temperature (Keangin, Vafai, & Rattanadecho, 2013). Keangin *et al.,(*2013) has reported that the temperature increment is expected to affect human's physiology such as malformations, temporary infertility in males, brain lesions, and blood chemistry changes and brain tumours (Keangin *et al.*, 2013; Wessapan, Srisawatdhisukul, & Rattanadecho, 2011).

SE (SE) is a parameter that describe how good an enclosure or material is in attenuating EM wave. Due to that, the SE measurement is required in this study. This research is focusing on EMI shielding methods, EMI shielding area (Construction/building), the study of construction materials and determines fillers for EMI shielding purpose in buildings. However, to set up a shielding room, it is not as easy as the cost to build up a shielding room which is made of metal material is very costly (Yee, 2015). The shielding room is available for only specific places like laboratory, hospital, and industry.

Table 1.1: Typical electric and magnetic field strengths measured near household appliances at various distance (Yee, 2015).

Electrical device	Electric field strength (V/m) at distance of 30cm	Magnetic field strength (μT)		
		3cm	30cm	1m
Stereo receiver	180	No information		
Iron	120	8-30	0.12-0.3	0.01-0.03
Refrigerator	120	0.5-1.7	0.01-0.25	<0.01
Mixer	100	No information		
Toaster	80	No information		
Hair Dryer	80	6-2000	0.01-7	0.01-0.03
Colour TV	60	2.5-50	0.04-2	0.01-0.15
Coffee machine	60	No information		
Vacuum cleaner	50	200-800	2-20	0.13-2
Electric Oven	8	No information		
Light bulb	5	No information		
Electric shaver	No information	5-1500	0.08-9	0.01-0.03
Microwave oven	No information	73-200	4-8	0.25-0.6
Electric oven	No information	1-50	0.15-0.5	0.01-0.04

In recent times, the use of by-product materials for the replacement of various industrial materials has been revitalized because of the environmental concerns (Balo & Yucel, 2013). Many researchers have invested in the modification of traditional materials in order to improve their user-friendliness. The industrial solid waste focuses in this research is palm oil fly ash. According to Malaysian Palm Oil Board (MPOB), Malaysia is one of the largest palm oil producers and exporters in the world MPOB

(Board, 2010; MPOB, 2016). Based on a study in 2007, it is found that the combustion of palm oil husk and palm kernel shell in the steam boiler has produced 3.1 million tonnes in Malaysia (Tangchirapat, *et al.*, 2007). These solid wastes were also used as a fuel in the boiler for electricity generation. The palm oil fuel/fly ash (POFA) generated from the combustion has reaching a level of 4 million tons in year 2013. (Zarina, *et al.*, 2013). Thus, this has attracting many researchers to use it as secondary raw material for reducing its environmental harm.

Since the chemical composition of POFA is containing high silicon dioxide, which met the pozzolanic properties criteria, it has the potential to be used as cement filler to produce strong and durable concrete and other cement-based works(Muthusamy & Azzimah, 2014). Besides that, the fly ash also has shown its potentialities for wave attenuation due to its complex components and porous structure (Baoyi, Yuping, & Shunhua, 2012). The POFA is containing high carbon content after the burning process. Hence, it can be employed in the construction and building materials for EMI mitigation. For this reason, extensive works is carried out in this research to characterize the POFA and optimize its mixing ratio as plastering mortar-POFA wall to mitigate the EMI.

An appropriate experimental design and optimization method is able to reduce the experimental cost. There are many optimization methods proposed by many researchers for the engineering field. The selection of suitable optimization method is one of the tasks in this research.

1.2 Problem statement of research

The development of technology nowadays has putting the society in an electromagnetic environment. According to WHO, tissue heating is the principal consequence as the results of interaction between radio frequency energy and the human body. Human beings are exposed to the electromagnetic wave from smartphones, and most of the energy is absorbed by the skin and other superficial tissues, leading in a negligible temperature rise in the brain and/or other organs of the body. Many researchers has claimed that this exposure can causes health hazards, such as symptoms of languidness, insomnia, nervousness, headache, immunological malfunction and so on (Fesenko, *et al.*, 1999; Levitt & Lai, 2010). Besides that, some

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